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Short communication

Comparing the energy required for fine grinding torrefied and fast heat treated pine

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ABSTRACT

The purpose of the study was to compare torrefaction to partial pyrolysis conducted with a fast heat treatment process. Both torrefaction and the fast heat treatment tests were performed in a bubbling fluidized bed reactor. The study investigated the anhydrous weight losses, the fine grinding energy requirements, and the lower heating values of the samples produced with the two methods i.e. torrefaction and the fast heat treatment. The effect of particle size to these quantities was also investigated. The measurements demonstrated that the fine grinding energy requirement decreased rapidly as a function of anhydrous weight loss. The overall energy content remaining in the solid product decreased linearly as a function of anhydrous weight loss. The study shows that there is only little difference in the final products of the two processes when using particle sizes less than 4 mm. This means that it is possible to get similar products from the fast heat treatment process that takes only seconds compared to the slower torrefaction process that takes minutes.

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1. Introduction

Depending on its origin biomass can be considered to be a carbon-neutral fuel source [1]. Biomass is also relatively evenly distributed around the world. Thus, it is very suitable for local energy production even if there is no well established national infrastructure for power generation. However, using biomass as an alternative fuel in already existing coal power plants is more complicated. A large proportion of these power plants operate by using pulverized fuel firing technology [2]. This means that in order to use biomass as a fuel source in these types of power plants; the fuel must first be ground into a suitable size fraction. The energy requirement for fine grinding fibrous biomasses is much higher than the energy required to grind fossil coal. One possible solution for lowering the energy required is to use heat treatment to achieve partial degradation of the holocellulose fraction in the biomass. This kind of treatment has a considerable impact on the fine grinding energy requirement [3]. Other challenges for the utilization of biomass in the already existing coal plants arise, for example, from the high alkali content of biomass materials. These challenges, however, are not discussed in this article [4].

Torrefaction is a process in which biomass is treated in temperatures under 300 °C [5]. Earlier studies have shown that the energy requirement of fine grinding decreases rapidly during torrefaction especially during the initial 10% mass loss [3]. Torrefaction, however, is a slow process, this is not desirable for industrial applications. A typical residence time of the feedstock in a pilot scale torrefaction reactor is

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10–60 min [6]. In this article torrefaction was compared to a more rapid heating process in which the particles undergo partial pyrolysis. The biomass for the tests was chosen to be Scots Pine (Pinus sylvestris). The rapid process in this study was chosen to last for 10 s, which is roughly the particle residence time in a circulating fluidized bed pyrolysator [7]. The idea was to compare the two processes by studying the evolutions of fine grinding energy requirement and lower heating value as a function of anhydrous weight loss.

2. Materials and methods

2.1. *Experimental procedure*

The wood samples examined in this study were sawed Pinus sylvestris timber. Torrefaction tests were conducted with 3 mm cubes. The fast heat treatment tests were conducted with 3, 4, 5, and 6 mm cubes. Both the torrefaction and the fast heat treatment tests were conducted in a laboratory scale bubbling fluidized bed reactor. After the thermal treatments, the mass loss of the samples was determined. The samples were fine ground and the grinding energy consumption was determined. For comparison a sample of high volatile C-bituminous fossil coal was also ground [8]. The coal sample was prepared by sieving a fraction using sieve sizes of 3.15 mm and 5 mm. The lower heating values of the pine samples were also determined.

2.2. *Sample preparation*

The samples were prepared by sawing pine plank with a band saw into different sized cubes. The cube sizes were selected to be 3, 4, 5, and 6 mm. The cube size of 3 mm was chosen because it was estimated to represent the smallest easily achievable chip size of an industrial chipper. This estimation was based on the average fiber length of pine. The cube size of 6 mm is the largest cube size suitable for easy operation of the necessary experimental setup for fine grinding energy requirement. Cube form was selected because it was considered to be the easiest to manufacture consistently. Furthermore, when using the cube form, the modeling of the internal heat transfer of the particles remains relatively simple. The sample size was approximately 5 g of oven-dry cubes.

2.3. *Bubbling fluidized bed reactor*

The bubbling fluidized bed reactor consisted of a flame resistant steel tube of which was 85.3 mm the inner diameter. Inside the tube was a kaowool grate which held a quartz sand bed in place. Pre-heated nitrogen was fed into the reactor from below the kaowool grate. The wood particles were fed into the reactor with a stainless steel cage. The residence time of the particles in the reactor was manually measured with a stopwatch. Manual measuring caused a small variation to the residence times due to human error. The temperature of the bed was constantly measured with a thermocouple placed in the sand. All sample particles were first oven-dried and weighed before feeding into the reactor. Quenching was done by removing the sample holding cage and submerging it into liquid nitrogen for a few seconds. After quenching the particles were oven-dried again to remove moisture that condensed from ambient air to the cold surface of the sample particles. Any remaining bed sand was removed from the samples and the samples were weighed.

2.4. *Setup for measuring the fine grinding energy requirement*

The main instrument of the fine grinding energy requirement setup was a Retsch ZM200 ultra-centrifugal mill. The mill was equipped with a 750 μm reinforced ring sieve and a 6 teeth stainless steel rotor. A Christ Elektronik CLM1000PP energy consumption meter was used for monitoring the power draw of the mill. The grinding energy requirement was calculated by subtracting the idle running power of the mill from the measured values. The idle running power of each run was determined by calculating an average of 10 s from the beginning of each measurement. The resulting power curve was then numerically integrated with the help of the trapezoidal rule. All grinding energy measurements were done with oven-dried samples which were allowed to cool down to room temperature in a desiccator for at least 15 min.

2.5. *Lower heating value*

The lower heating values of the samples were determined by Labtium Ltd. according to the CEN/TS 14918 standard. The heating values given in the results are calculated from the calorimetric heating values by subtracting a constant value of 1.349 MJ/kg from them [9].

3. Results and discussion

3.1. *Anhydrous weight loss*

The anhydrous weight loss of the torrefied samples was studied and the results are presented in Table 1.

The results for the anhydrous weight loss in the fast thermal treatment tests are given as a function of temperature and cube size, since the residence time was kept constant. The results are shown in Fig. 1.

Some of the measured points in Fig. 1 are inconsistent. This is most likely due to the inaccuracy in the manual residence time measurement or the heterogeneous nature of the samples.

Table 1 – The anhydrous weight loss (%) of torrefied pine.

Time (s)	Temperature			
	250 °C	275 °C	300 °C	325 °C
30	0.9	1.2	1.8	2.2
60	1.4	2.1	3.9	8.3
180	2.6	5.5	10.6	18.2
300	3.5	7.4	14.5	26.4
1800	7.1	18.4	32.8	56.0

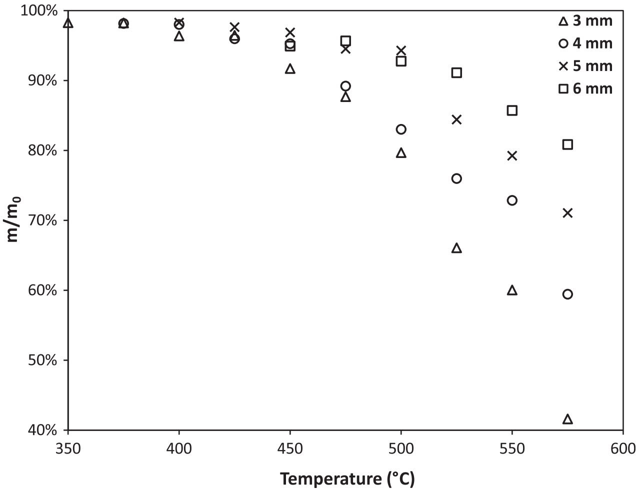

Fig. 1 – The anhydrous weight loss of the fast heat treated pine.

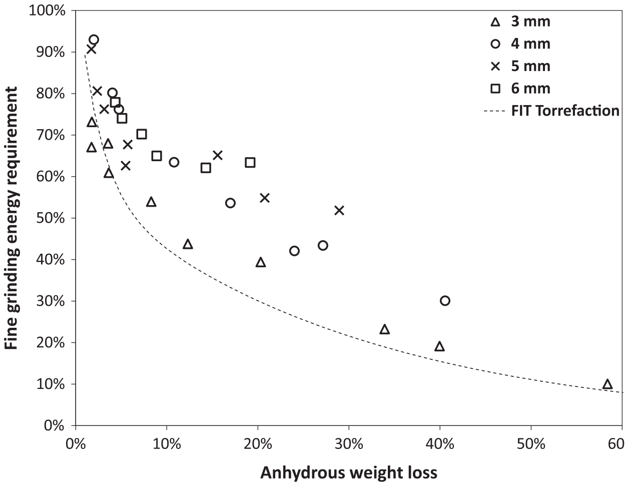

Fig. 3 – The fine grinding energy requirement for the fast heat treatment process and torrefaction as a function of anhydrous weight loss.

3.2. *Fine grinding energy requirement*

The fine grinding energy requirement was first measured for the torrefied samples. Since the fine grinding energy requirement is dependent on the grinding method, the figures are shown as percentual change compared to the untreated sample fine grinding energy requirement. This also makes the comparison of the different particle sizes more feasible since the fine grinding energy requirement also depends on the particle size. The fine grinding energy requirement for the fossil coal sample was compared to the fine grinding energy requirement of the raw 3 mm pine sample. The results are given in Fig. 2.

The results shown in Fig. 2 have a similar decreasing trend as those presented in Repellin et al., 2010 [3]. However, due to the difference in the ring sieve size, direct comparison of the results is not possible. A function fit for the grinding energy requirement as a function of mass loss was made for the torrefied samples. This was done for the purpose of comparing of the two processes i.e. torrefaction and fast heat treatment. The comparison and the results of the fine grinding energy requirement for the fast heat treatment process are presented in Fig. 3.

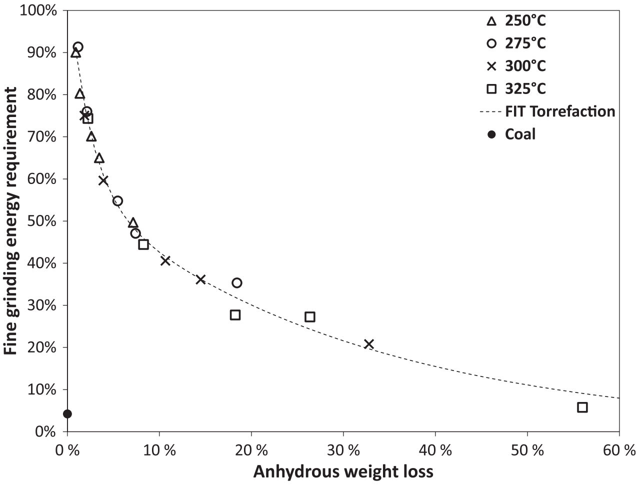

Fig. 2 – The fine grinding energy requirement for the torrefied samples as a function of anhydrous weight loss.

The fine grinding energy requirement measurement points for the 3 mm sized cubic particles seem to be very near to the curve fit obtained from the torrefied samples. As the particle size increases, the measurement points shift upwards and to the right from the curve, especially for weight loss values above 5%. There are some inconsistencies in the 5 mm particle size behavior compared to the 4 mm particle size. The difference is probably the result of a measurement error related to the grinding process.

3.3. *Lower heating value*

The results for the lower heating values of the torrefied wood samples are given in Fig. 4.

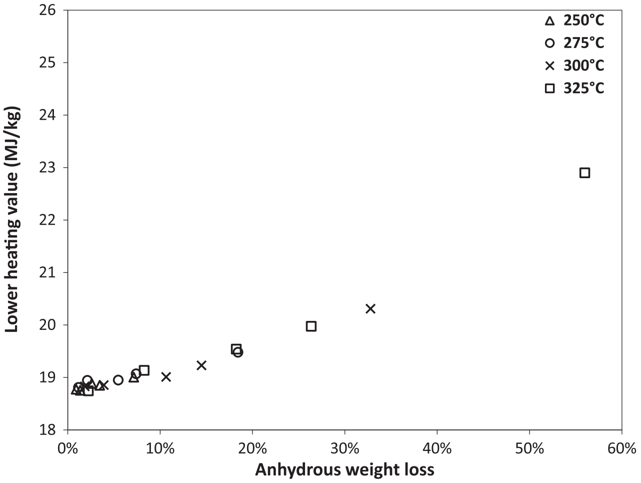

Fig. 4 – Lower heating values for the torrefied samples as a function of anhydrous weight loss.

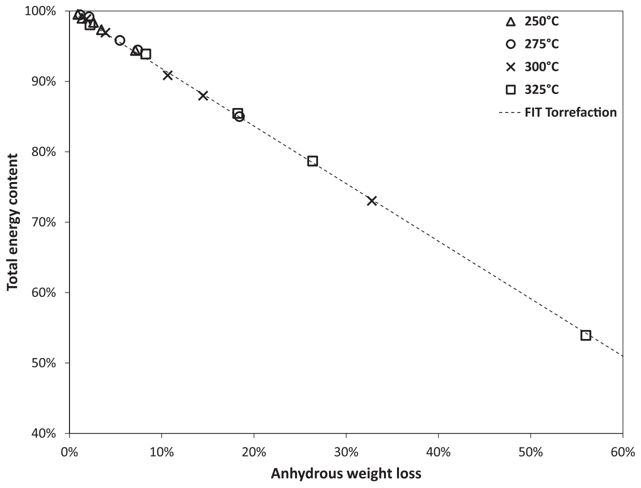

Fig. 5 – The total energy content of the solid product as a function of anhydrous weight loss.

Fig. 4 shows that the lower heating value of the samples clearly increase as a function of anhydrous weight loss. The ratio of the total energy content remaining in the solid product to the raw sample energy content is presented in Fig. 5.

By looking at Fig. 5, it is clear that even though the lower heating value of the samples increases, the net loss of energy is a linear function of anhydrous weight loss. A linear function fit was created in order to compare torrefaction and the fast heat treatment process. The comparison of the two methods is presented in Fig. 6.

Fig. 6 indicates that there is only little difference in the behavior of the total energy content for the two processes. However, the fast heat treatment process seems to lose slightly more of the total energy content from the solid as a function of anhydrous weight loss compared to the slow torrefaction process. A probable cause for this behavior is that in the fast heat treatment process the surface of the particle is almost completely charred while the center of the particle hardly reacts at all.

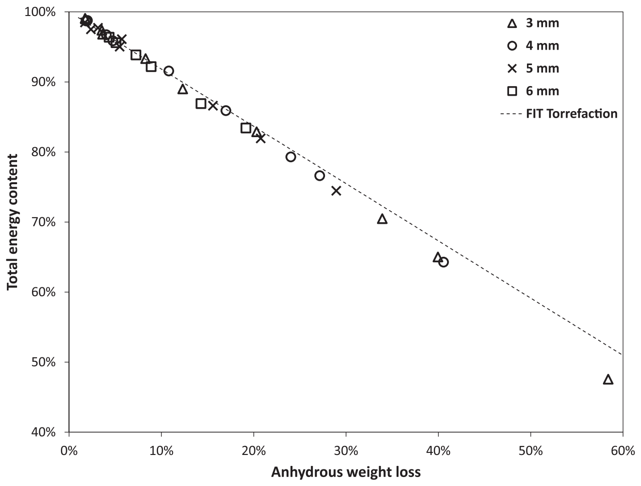

Fig. 6 – A comparison of the total energy content for fast heat treatment process and torrefaction.

4. Conclusion

The results for the torrefied samples are similar to those already presented in literature and therefore they are suitable when comparing of the two thermal pre-treatment methods [3,10]. The results from the fast heat treatment method indicate that it is a promising way to conduct torrefaction with smaller process units and with shorter residence times. However, the fast process has some disadvantages: more energy for fine grinding is required and slightly more of the solid's energy content is lost due to a conversion gradient in the particles. Nevertheless these disadvantages are only marginal when using a particle size less than 4 mm.

The financial feasibility of the two processes can be evaluated according to the results obtained from the study presented in this article. The mutual dependency of the fine grinding energy requirement and the total energy content left in the solid is now known. For a more thorough investigation of the financial feasibility one must also know the investment costs of the both processes, and the price of fine grinding energy compared to the price of the feedstock. A key issue is to find out how much conversion is really needed in order to reach the desired properties of torrefied fuel, for example, how much of the fine grinding energy requirement must be removed before the grindability is considered to be adequate. The storage properties of the torrefied fuel must also be studied to estimate the adequate stage of conversion.

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